

# Climate Change: What's ahead for the Southwest?

## *Goal of talk:*

*review evidence for “global warming” and what's at stake*

- *what's the consensus among climate scientists*
- *what's new - focus on the Arctic and implications*
- *what's new - focus on the Southwest U.S. and....  
the drought!.*



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Professor of Geography & Regional Development  
Professor of Atmospheric Sciences

*Acknowledgements:*  
Jonathan Overpeck  
Shoshana Mayden

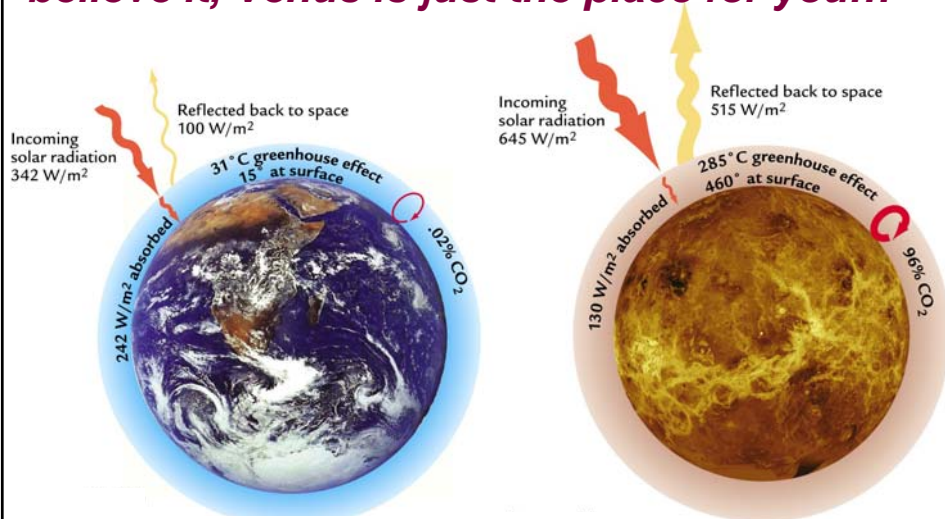
THE UNIVERSITY OF  
**ARIZONA**  
TUCSON ARIZONA

## *Pop-quiz!*

*For 10 points, answer the  
following question...*

***Is the “greenhouse effect”  
real, and how do we know?***

## The Greenhouse Effect... if you don't believe it, Venus is just the place for you...



**The Earth** is 15°C on average  
(would be frozen solid w/o CO<sub>2</sub>)

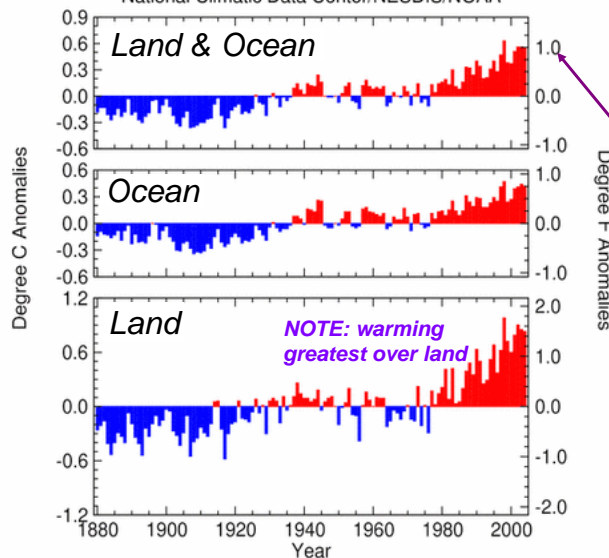
**Venus** = 460°C on average

From: Ruddiman, 2001

## "Global Warming" is real too...

Jan - Dec Global Surface Mean Temp Anomalies

National Climatic Data Center/NESDIS/NOAA



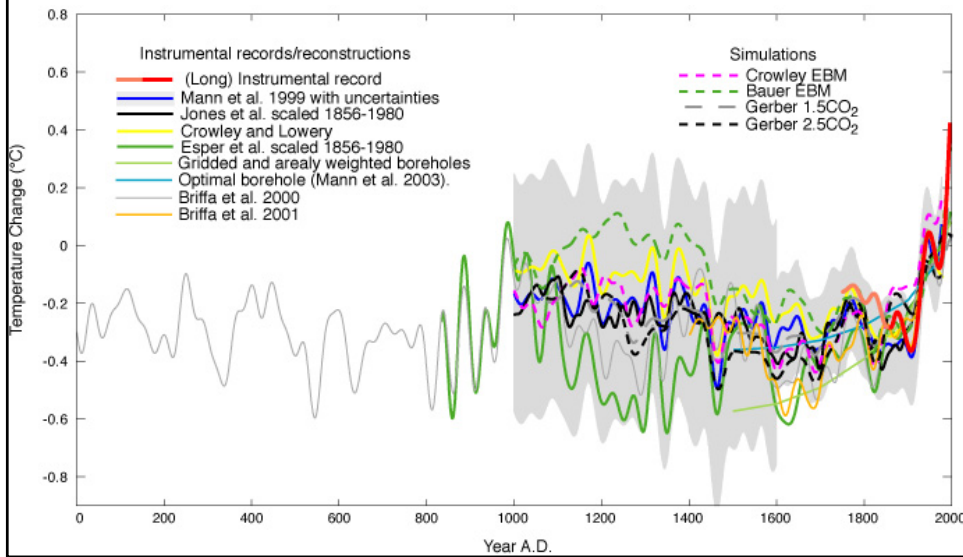
2004 = almost  
2nd warmest  
on record

8 of top 10  
warmest years  
have occurred in  
the last decade!

Unprecedented?

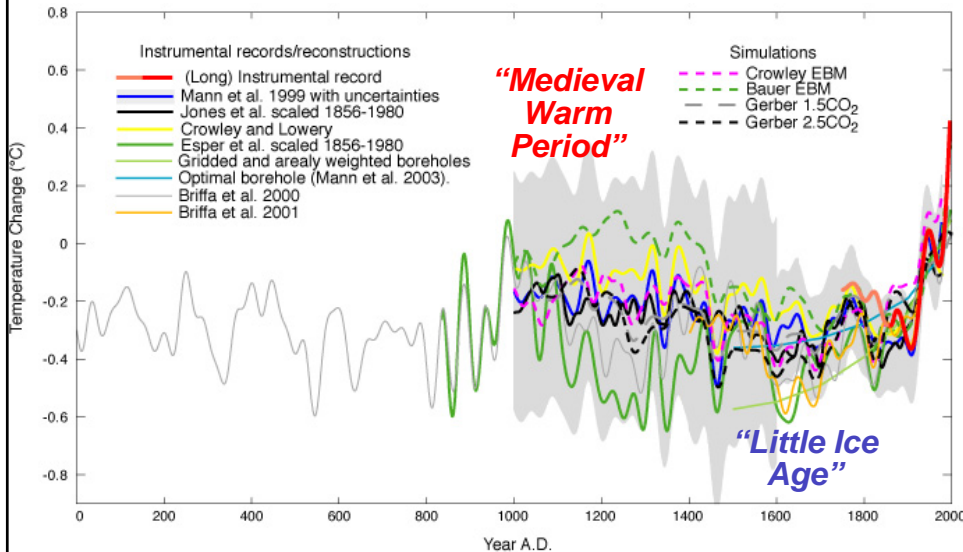
## Latest view of last 2000 years of Northern Hemisphere Temperature Change

Mann, M.E., Ammann, C.M., Bradley, R.S., Briffa, K.R., Crowley, T.J., Jones, P.D., Oppenheimer, M., Osborn, T.J., Overpeck, J.T., Rutherford, S., Trenberth, K.E., Wigley, T.M.L. (EOS, 2003)



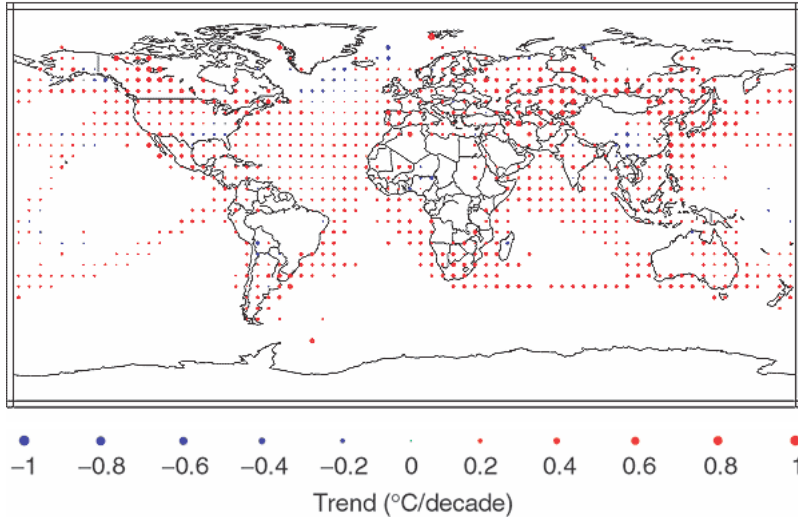
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## Instrumental Observed Temperature Trends - **ANNUAL**

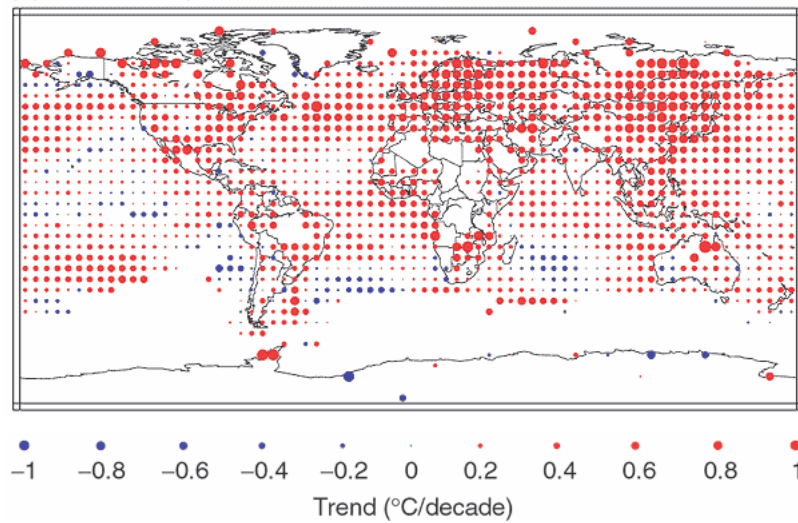
(a) Annual temperature trends, 1901 to 2000 **Note**



IPCC TAR (2001)

## Instrumental Observed Temperature Trends - **ANNUAL**

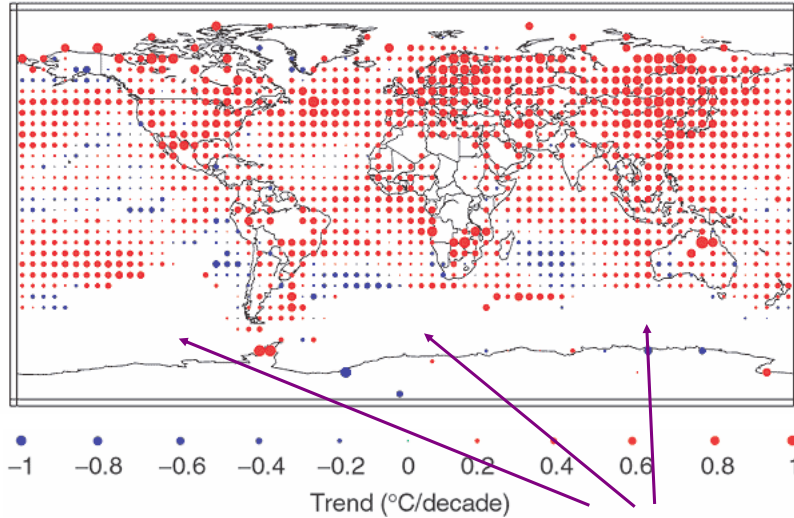
(d) Annual temperature trends, 1976 to 2000 **Note**



IPCC TAR (2001)

## Instrumental Observed Temperature Trends - **ANNUAL**

(d) Annual temperature trends, 1976 to 2000 ← **Note**

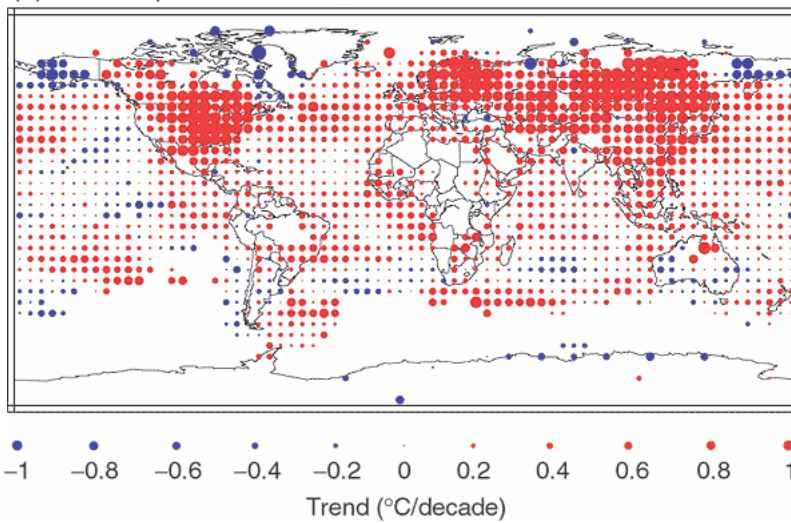


IPCC TAR (2001)

Large/deep ocean warming

## Instrumental Observed Temperature Trends - **Winter**

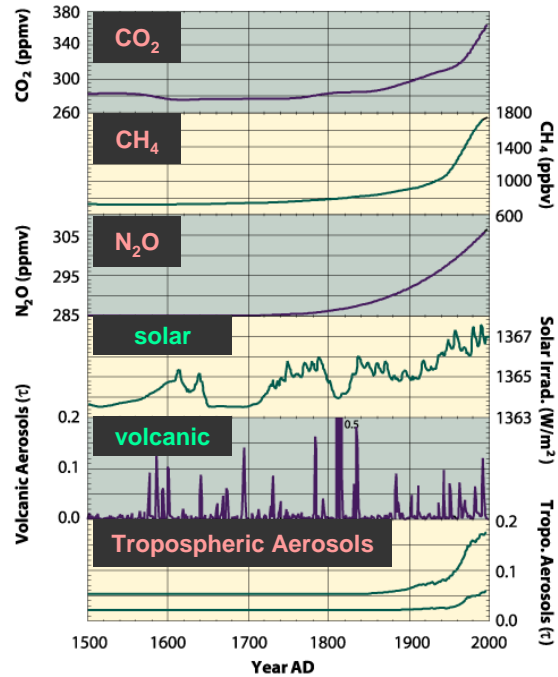
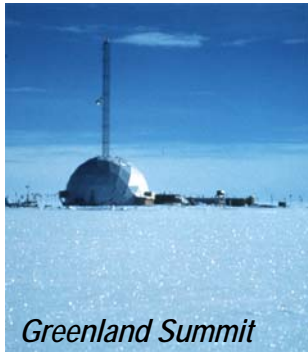
(a) DJF temperature trends, 1976 to 2000 ← **Note**



IPCC TAR (2001)

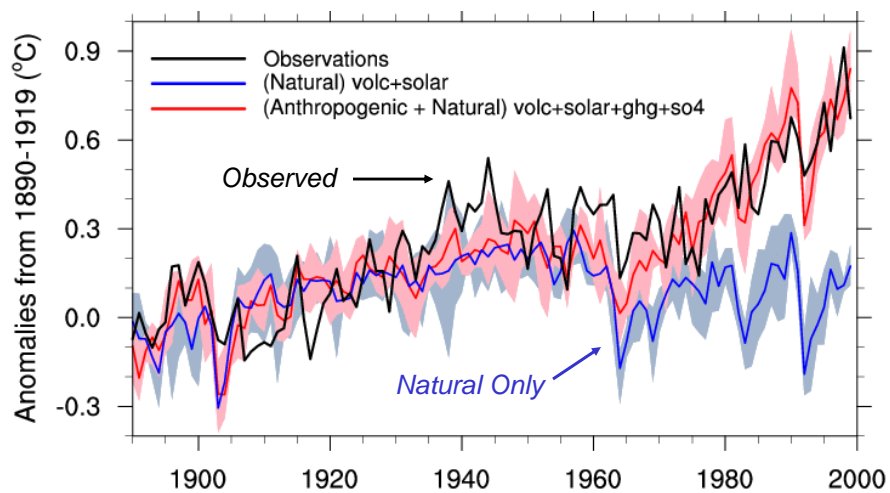
## Hypothesized climate forcing time series for the last 500 years

Robertson et al.,  
J. Geophys. Res. (2001)



## PCM - 20<sup>th</sup> Century Experiments

Forcings: Combined Natural+Anthropogenic and Natural only



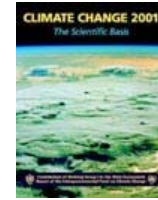
Meehl et al. (2004)



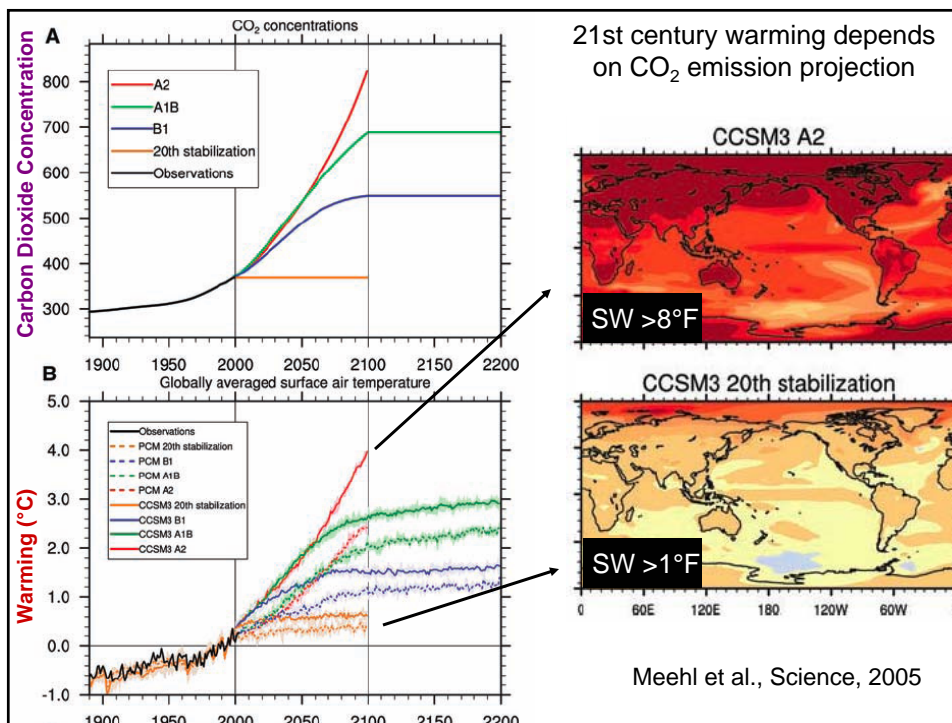
**The Intergovernmental Panel on Climate Change (IPCC)**  
***Climate Change 2001:***

Hundreds of authors and hundreds of reviewers,  
from most countries of the world

**All climate scientists!**



“globally averaged surface temperature  
projected to increase by **1.4 to 5.8°C** (**2.5 to 10.4°F**)  
over the period 1990 to 2100”



So, what is ahead? Big change? Little Change?



### *Climate Warming in the Arctic Significant and Accelerating*

- **Warming greatest on planet:** as predicted by IPCC
- **Arctic Sea Ice Pack:** thinned by 40% in last 50 years
- **Summertime Arctic Sea Ice:** melting is accelerating
- **Greenland Ice Sheet:** ditto, 16% increase in melt area between 1979 and 2002



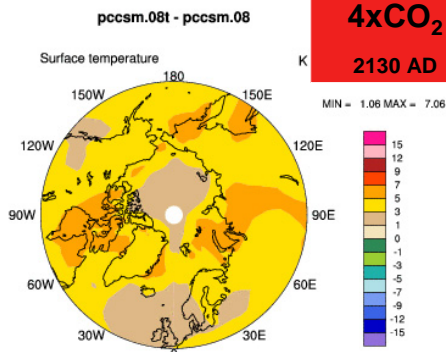
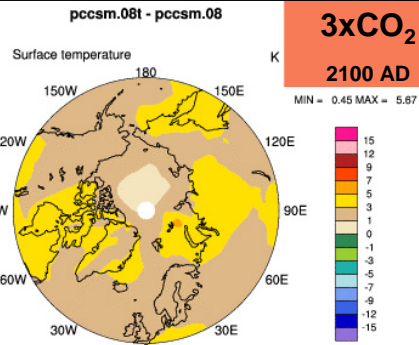
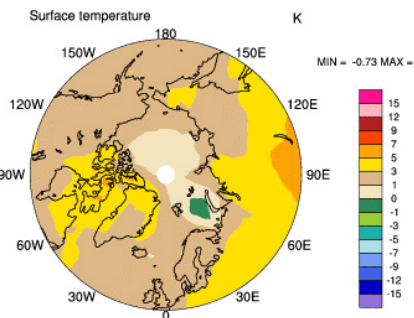
( Arctic Impacts of Global Warming, Cambridge U. Press, 2004)



### Paleoclimatic Lesson:

*Given no change in greenhouse gas emissions, the earth will be warm enough to melt at least 3 to 6 meters (10-25 feet) of sea level by the end of this century*

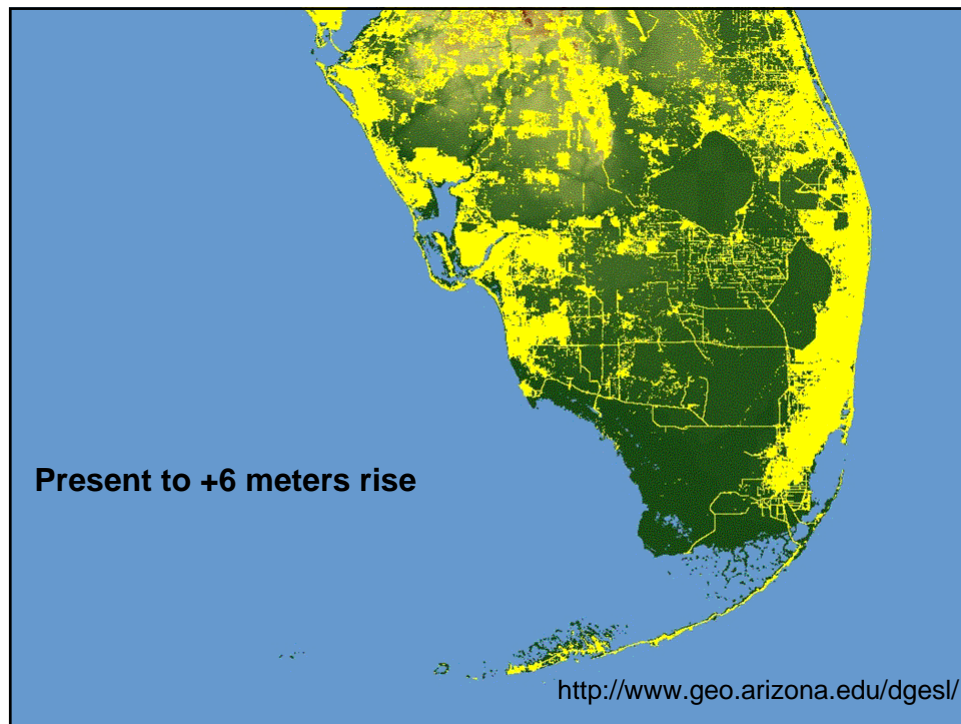
#### Last Interglacial



<http://www.geo.arizona.edu/dges/>

+6 meters

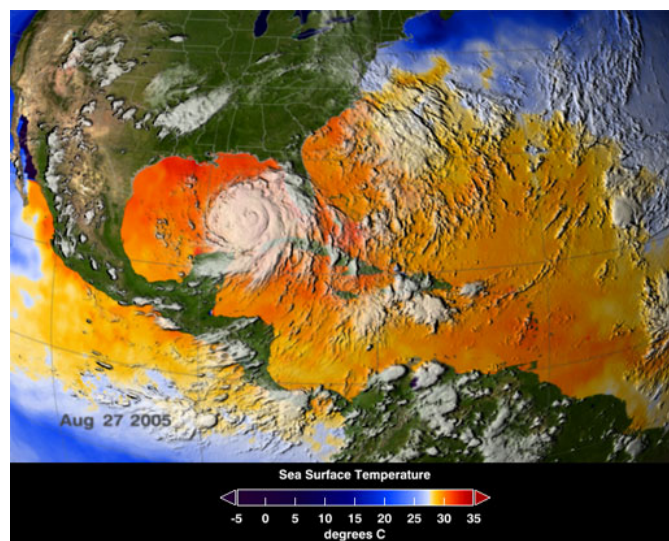
Plan now  
for new  
beachfront  
property!



*Is there more to worry about?*

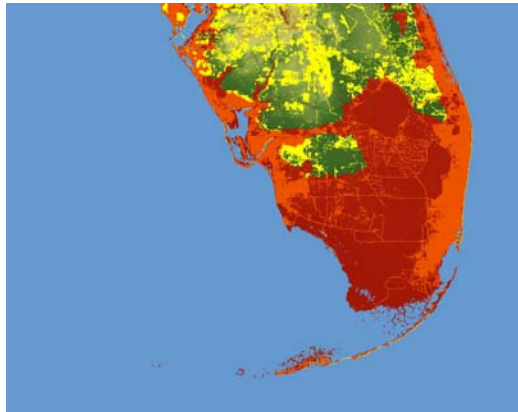
**"Increase  
in tropical  
cyclone  
peak wind  
intensities  
likely in  
some  
areas"**  
IPCC, 2001

**Hurricane Katrina**



*So, who's likely to feel BIG impacts first?*

*East and Gulf Coasts, and especially Florida?*



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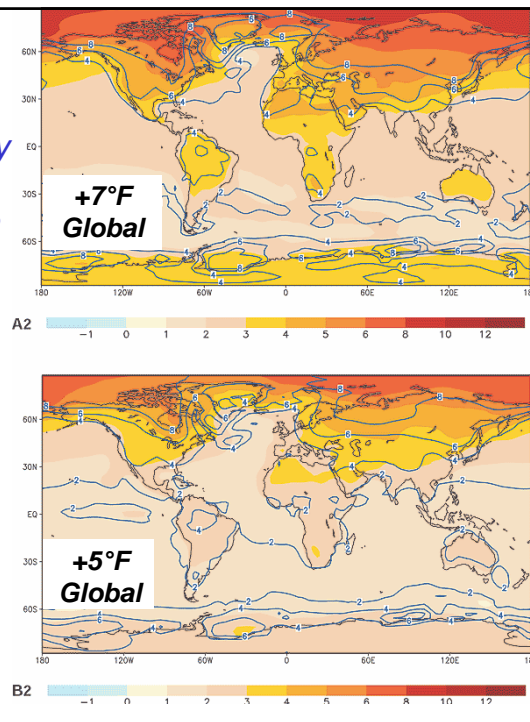
*Maybe not...*

**Annual Mean  
Temperature Change:**  
Late 20<sup>th</sup> to Late 21<sup>st</sup> Century

Average of model simulation  
ensembles = shaded colors

Predicted **warming greater  
over land** and at higher  
latitudes - just as observed  
so far

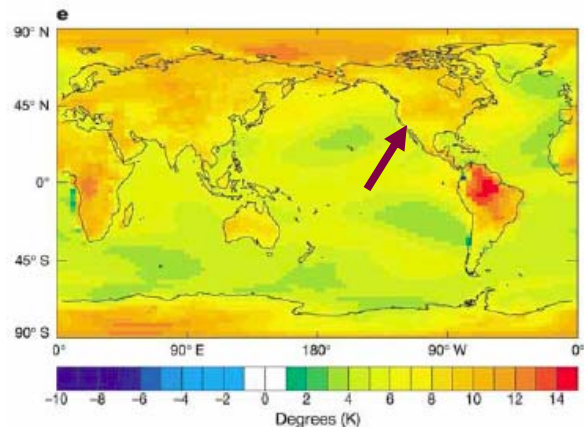
IPCC (2001)



For **Southwest**? Best bet is that we'll see the  
following by the late 21st century:

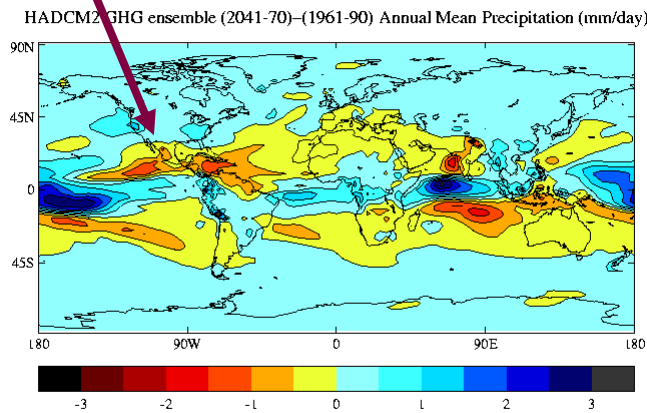
**temperature:** up to **14°F (or even more!\*)** warming,  
more probably in winter than summer

\*climateprediction.net -  
Stainforth et al., 2005  
*Nature*



For **Southwest**? Best bet is that we'll see the following by the late 21st century:

**precipitation:** flip a coin for changes in the mean, (**winter increase** more likely)



For **Southwest**? Best bet is that we'll see the following by the late 21st century:

**temperature:** up to 14°F (or even more!\*) warming, more probably in winter than summer

**precipitation:** flip a coin for changes in the mean, (**winter increase** more likely) plus:

- **snow runoff** season will be significantly shorter
- **evaporation** will be significantly higher in all seasons

Accelerated hydrologic cycle {

- **droughts** will be more likely
- **floods** will be more likely

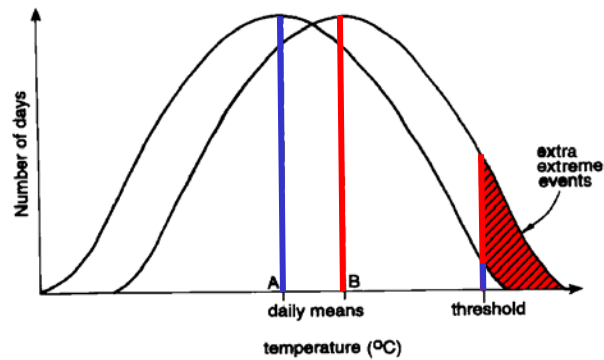


## A "Small" Change in the Mean Can Lead to a Large Change in Extremes

Droughts?

Floods?

Heat Waves?

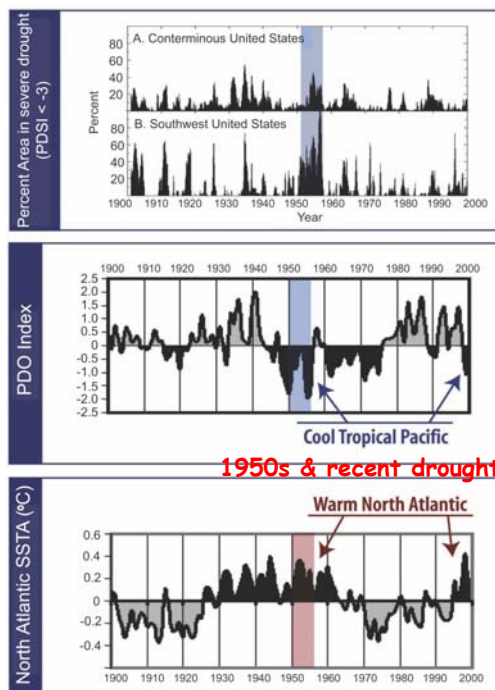


## Multi-Decadal Ocean- Atmosphere Variability

Another big drought?

What if we add the  
warming trend to this?

Source: Julio Betancourt

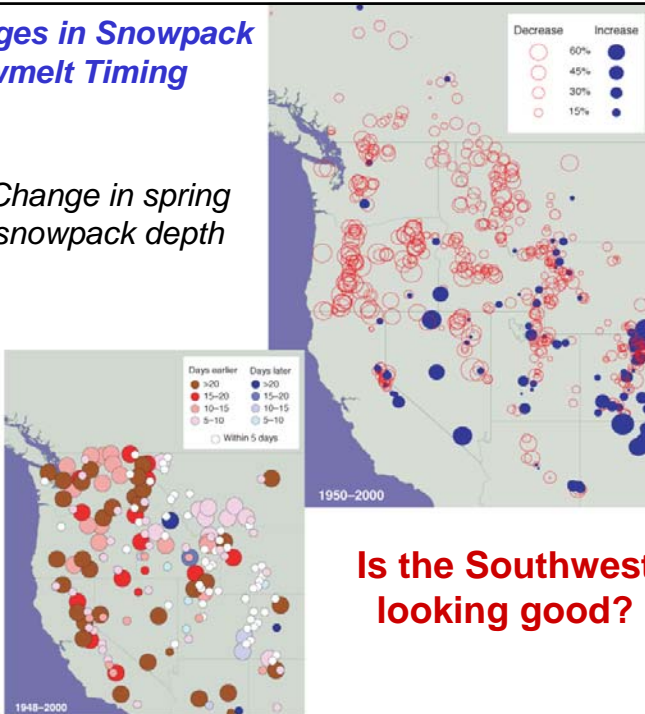


## Observed Changes in Snowpack Depth and Snowmelt Timing (1950 to 2000)

Change in spring snowpack depth

Change in timing of peak spring snowmelt

From: Service, 2004;  
adopted from Mote,  
Hamlet and Clark, 2004



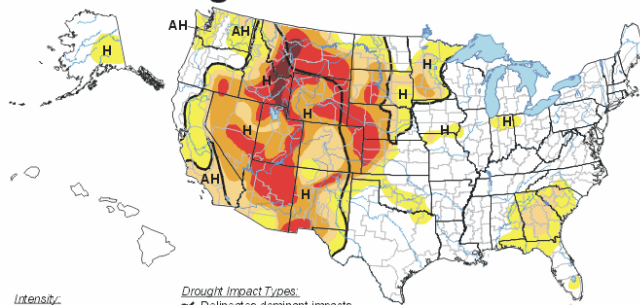
Is the Southwest looking good?

## Remember the Drought?

Durations and intensities are likely to change, and impacts too...

### U.S. Drought Monitor

May 18, 2004  
Valid 8 a.m. EDT



#### Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

#### Drought Impact Types:

- ~ Delineates dominant impacts
- A = Agricultural (crops, pastures, grasslands)
- H = Hydrological (water)
- A,H = Agricultural and Hydrological (No type = Both impacts)

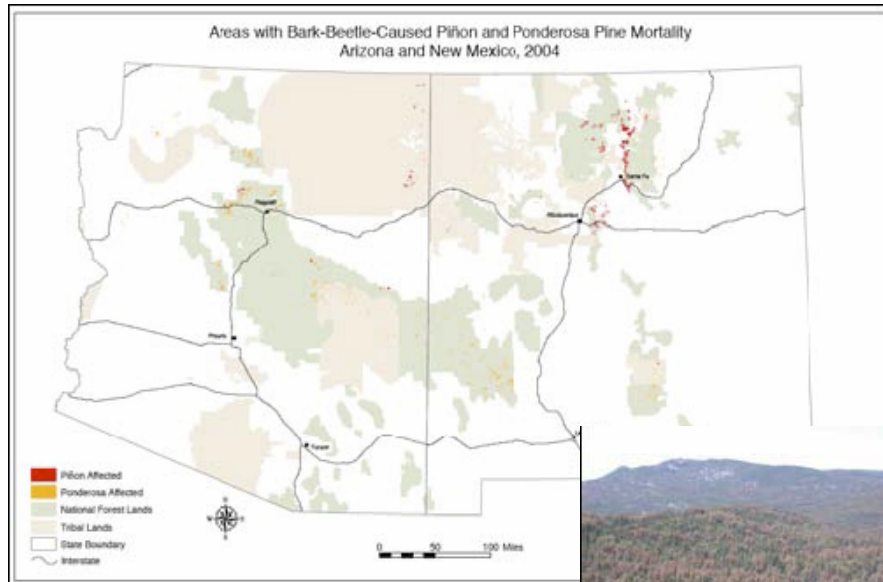
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

<http://drought.unl.edu/dm>



Released Thursday, May 20, 2004  
Author: David Miskus, JAWF/CP C/NO AA

*By 2002, Over 3 million acres of forest affected by tree mortality*



<http://www.fs.fed.us/r3/resources/health/beetle/index.shtml>



*Large crown fires - now occurring in some pine forests in the western US where they are historically and ecologically anomalous.*



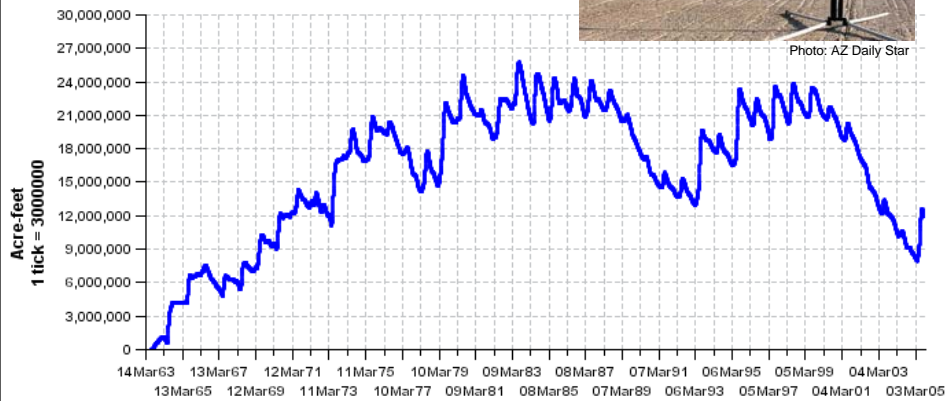
**Rodeo-  
Chedeski  
Fire (2002)  
460,000+  
acres**



**Note** - Current drought began in 1996 - Lake Powell currently down to 52% capacity - it will take at least 10 years to fill *if snow pack stays above normal* (not likely)

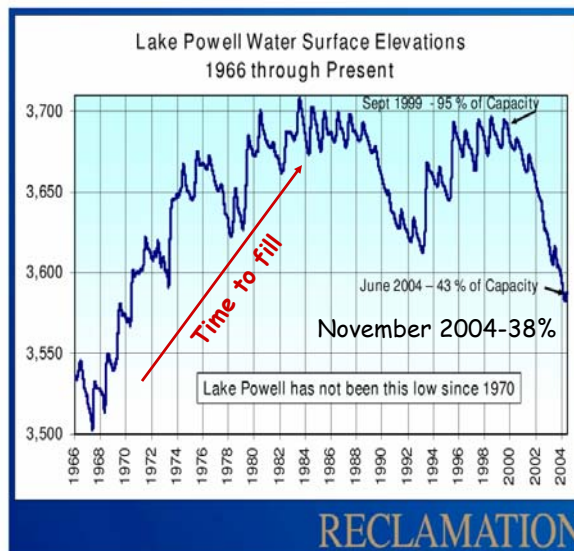


Photo: AZ Daily Star



<http://www.usbr.gov/uc/crsp/charts/>

Date 1 major tick = 1 year



### Refilling Lake Powell

>20 yrs w/ average Inflow

Back-to-back 1983-1984 would fill lake only to 90% capacity

Equalization requires that Lake Powell & Lake Mead fill together

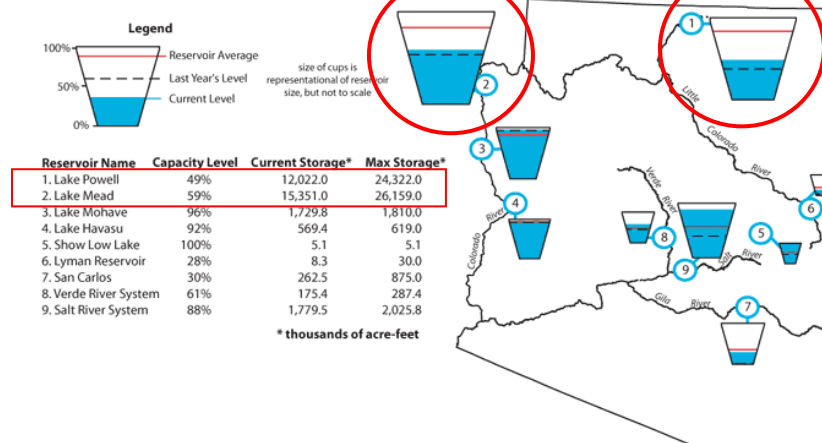
Wet "cycle" needed to refill both lakes

1965-1988 third wettest Period in last 750 yrs in Upper Colorado

Withdrawals = Inputs

# CLIMAS Southwest Climate Outlook

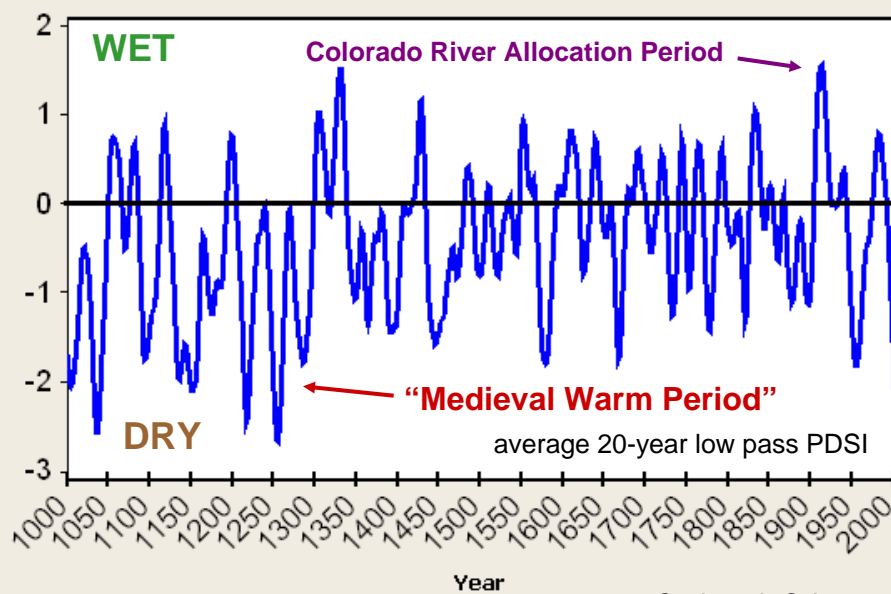
**Figure 5.** Arizona reservoir levels for August 2005 as a percent of capacity. The map also depicts the average level and last year's storage for each reservoir, while the table also lists current and maximum storage levels.



<http://www.ispe.arizona.edu/climas/forecasts/swoutlook.html>

## Ten Centuries of Southwest Hydrologic Status

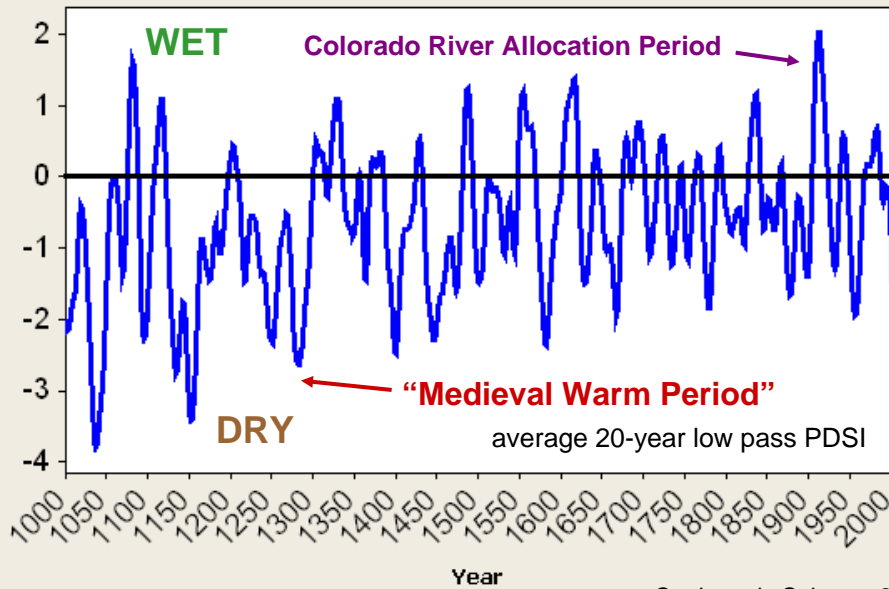
- the tree-ring record -



Cook et al., Science, 2004



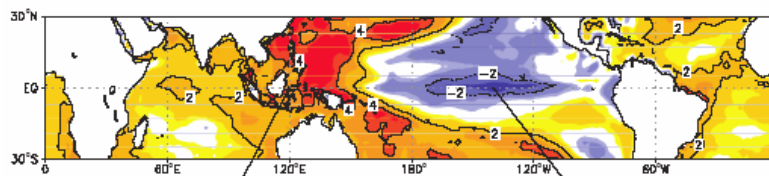
## Ten Centuries of **Southern Colorado** Hydrologic Status - the tree-ring record -



Cook et al., Science, 2004

## The Perfect Ocean for Drought

Martin Hoerling<sup>1\*</sup> and Arun Kumar<sup>2</sup>



Science, (2003)

*Interrupted by weak El Niño in  
Winter 2004-5?*

*Will the dry winters come back?*

# Colorado River flow

## Annual discharge

**Legally allocated flow** 16.5 maf

**Measured flow, 1902-1932** 15.8 maf

## Estimates of past flow:

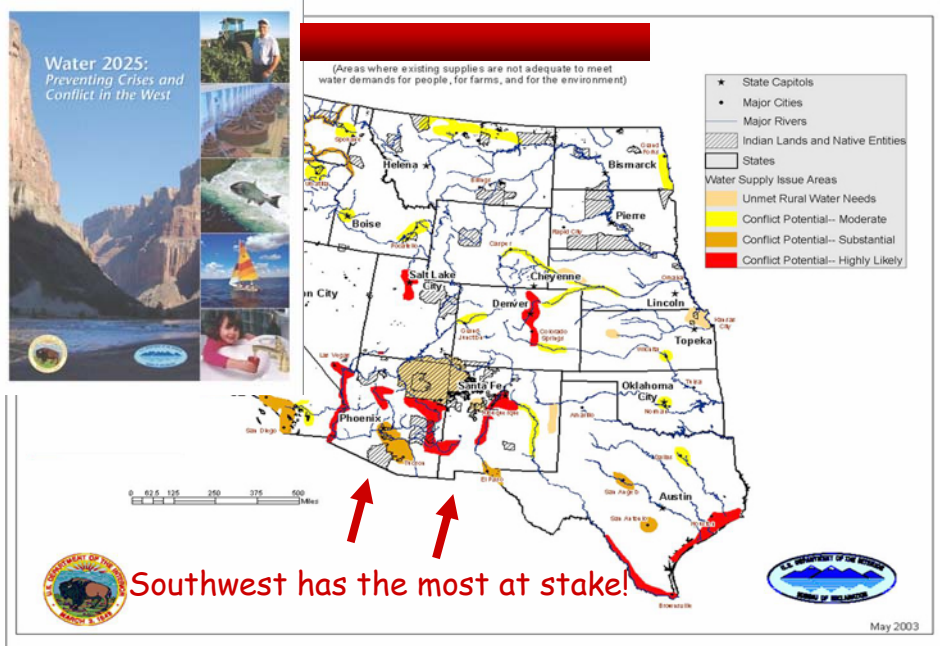
**Tree rings, upper basin, 1512-1961** 13.5 maf

**Isotopes, delta clams, 1500-1950** 12.5 maf

(New UA Research  
- Prof. Karl Flessa and team)

Michael Collier photo, 1999

**So, the new federal water warning seems on target...**



## **Conservative estimates of *climate change* impact on the **Colorado River System** by *the end of 21st century***



Christensen et al., *Climatic Change* (2004)

- Annual runoff down by over 15%
- Basin storage down by 40%
- Power output decreased to 45-56% of historical average
- Central Arizona Project (CAP) hit hard

## **Conclusions - the science**

- *decades-long drought possible even w/o anthropogenic climate change, especially during warmer periods*
- *given continued greenhouse gas emissions, future climate change will be substantial and persistent:*
  - substantial warming a sure bet
  - substantial increase in evaporation a sure bet
  - decreased snowpack and snow season likely
  - some increases in precipitation (esp. winter) possible, but best bet on less than in wet years of 20th century
  - likely increase in drought frequency and duration
  - current drought (hot and dry) should be considered a harbinger of things to come, unless we act soon

## Conclusions - what to do?

- ways to ensure best chance for **continued economic growth**, **quality of life**, and **healthy ecosystems** include:
  - 1) ADAPT SMARTLY - *implement policy to reduce climate vulnerability (e.g., to high temperatures, water shortages and climatic extremes)*
  - 2) MITIGATE DANGEROUS CHANGE - *lead efforts to curb climate change - West will likely be the first part of the U.S. to suffer major impacts*

NOTE: both are “**no regrets strategies**” that have serious benefits beyond climate change (e.g., energy independence, improved air quality, and new economic growth engines)

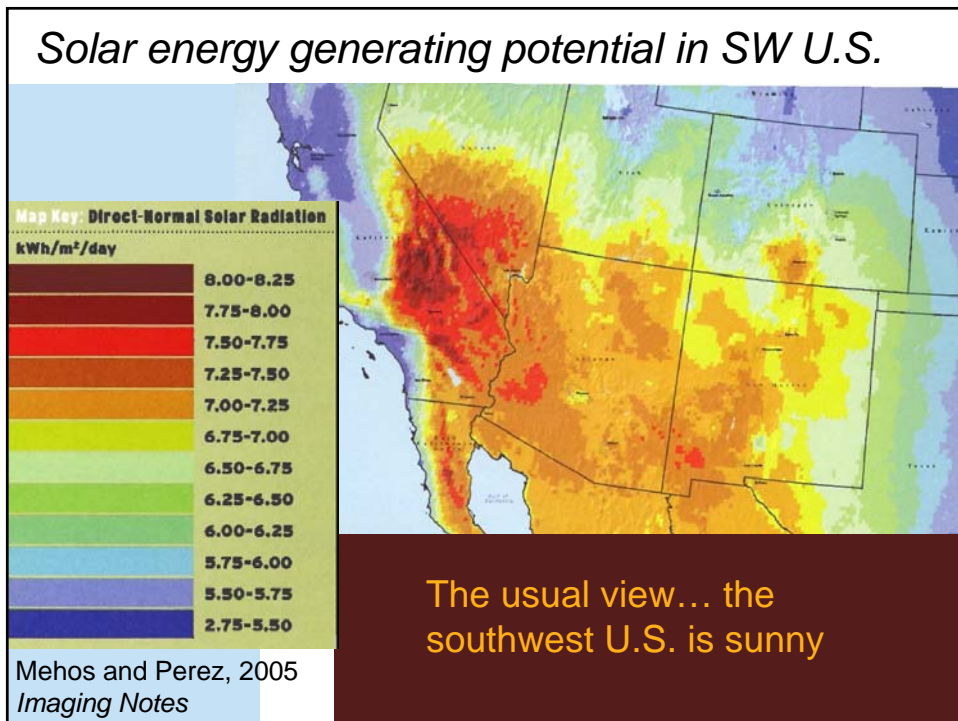
*“The end of the **stone age** did not end for lack of stone, and the **oil age** will end long before the world runs out of Oil” (Sheikh Yamani - former Oil Minister of Saudi Arabia)*

### What's needed:

- 1) Increased focus on **no-regrets energy and water conservation measures**
- 2) A **Manhattan Project**-like effort to develop the energy sources of the future
- 3) Need to **start soon** to avoid big impacts

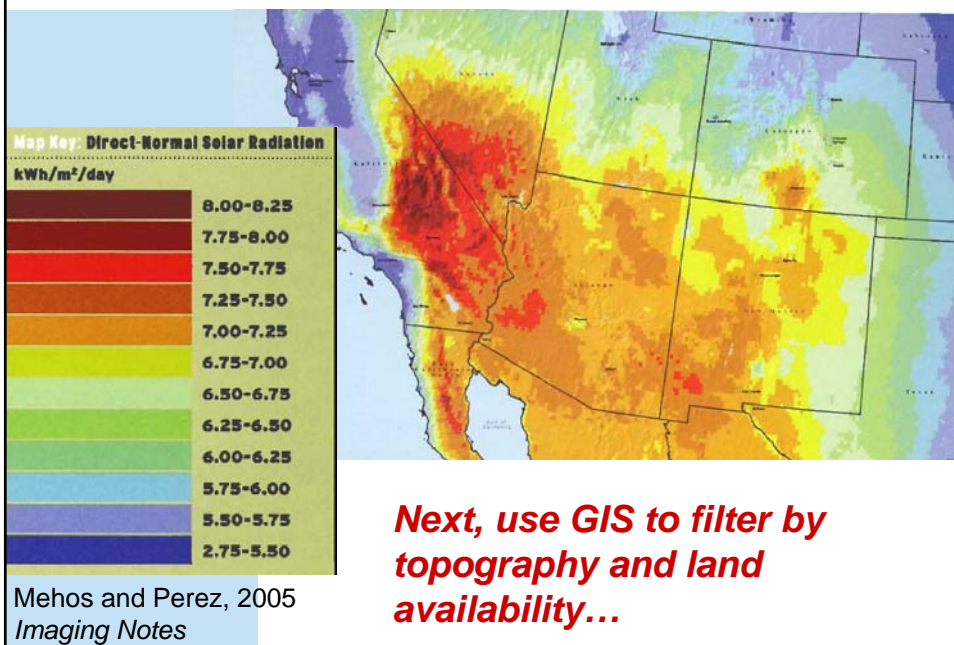




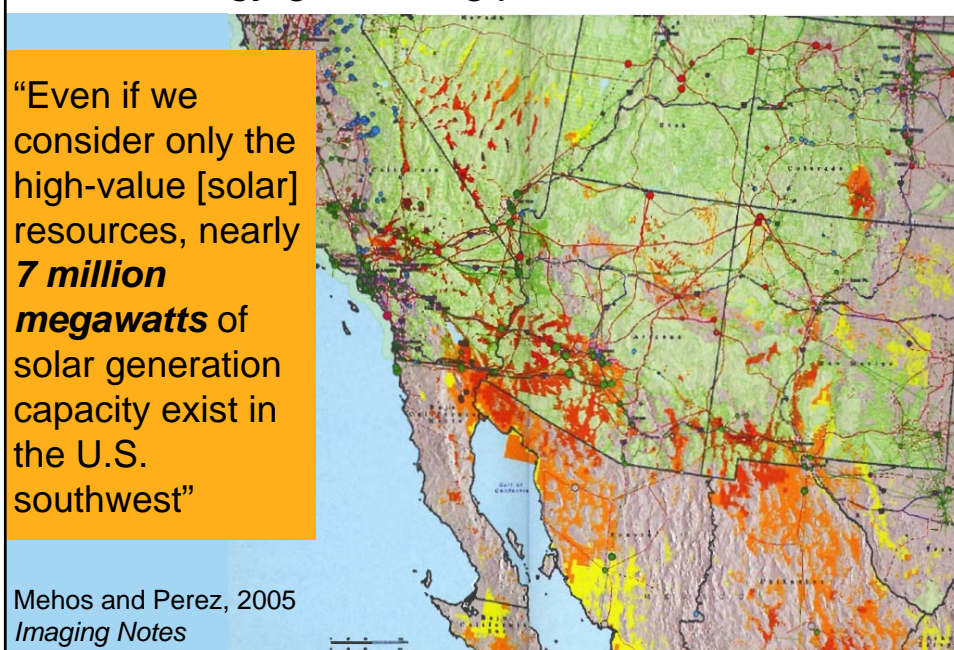




## Solar energy generating potential in SW U.S.



## Solar energy generating potential in SW U.S.



### Pop-quiz #2

For another 10 points, answer the following question...

**What is the current TOTAL U.S. electricity generation capacity?**

**~1 million megawatts (MW)**

76% fossil fuel

11% hydro

11% nuclear

2% geothermal, solar, & wind

Source: US Department of Energy

<http://www.eia.doe.gov/emeu/cabs/usa.html>

### Solar energy generating potential in SW U.S.

**Table 1.** Results of satellite/GIS analysis showing area of land and associated power capacity for seven states in U.S. Southwest.

STATE	AVAILABLE AREA (MI <sup>2</sup> )	CAPACITY (MW)*
Arizona	19,300	2,467,700
California	6,900	877,200
Colorado	2,100	271,900
Nevada	5,600	715,400
New Mexico	15,200	1,940,000
Texas	1,200	148,700
Utah	3,600	456,100
<b>Total</b>	<b>53,900</b>	<b>6,877,000</b>

\*CSP power plants require about 5 acres of land area per megawatt of installed capacity. Solar generation can be estimated by assuming an average annual solar capacity factor of 25%-50%, depending on the degree of thermal storage used for a plant.

Mehos and Perez, 2005 *Imaging Notes*



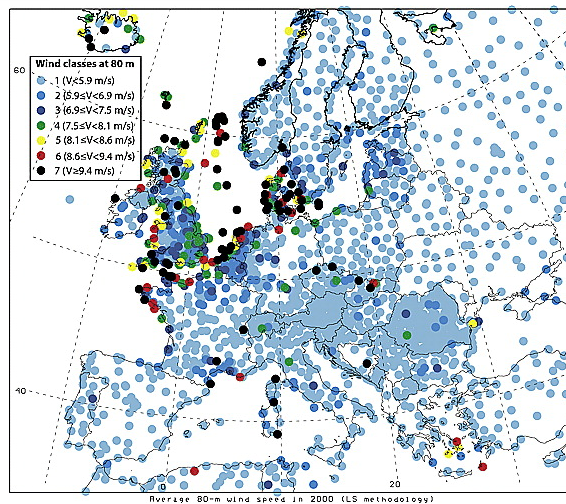
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 110, D12110, doi:10.1029/2004JD005462, 2005

## Evaluation of global wind power

Cristina L. Archer and Mark Z. Jacobson

### Europe

(including Denmark,  
which already  
generates 20% of its  
electricity from wind)

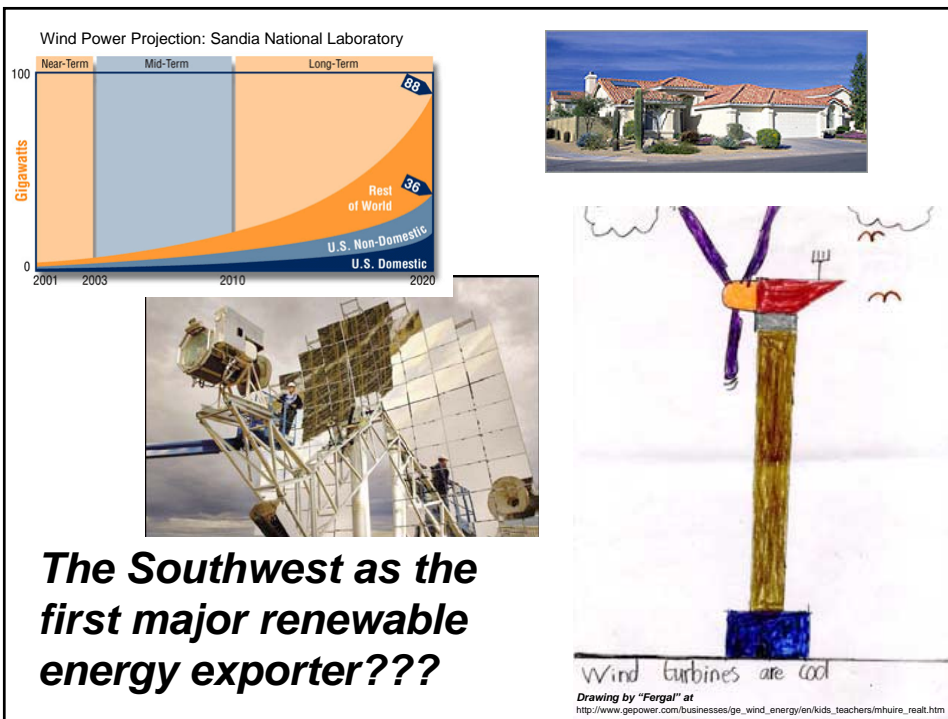
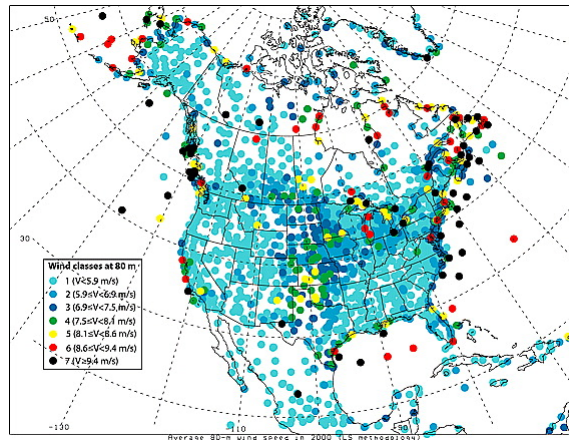




## Evaluation of global wind power

Cristina L. Archer and Mark Z. Jacobson

**North America**  
(greatest wind power potential?)



**The Southwest as the first major renewable energy exporter???**

Drawing by "Fergal" at  
[http://www.gepower.com/businesses/ge\\_wind\\_energy/en/kids\\_teachers/mhuire\\_realt.htm](http://www.gepower.com/businesses/ge_wind_energy/en/kids_teachers/mhuire_realt.htm)

***Thank You!***

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